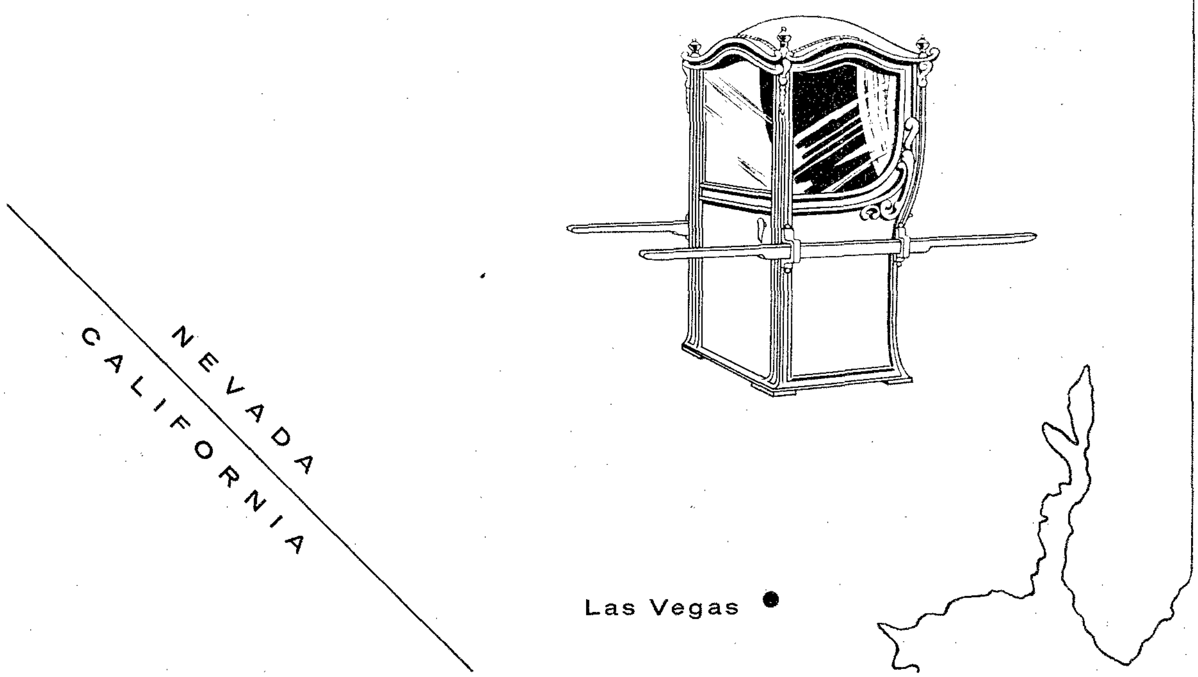
PNE-235F
FINAL REPORT

Plowshare / peaceful uses for nuclear explosives

UNITED STATES ATOMIC ENERGY COMMISSION / PLOWSHARE PROGRAM

project SEDAN

NEVADA TEST SITE / JULY 6, 1962



Seismic Velocity Study

S. E. Warner

LAWRENCE RADIATION LABORATORY ISSUED: MAY 15, 1963

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PROJECT SEDAN

PNE-235F

PROJECT 2.05

SEISMIC VELOCITY STUDY

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Livermore, California

December 1962

ABSTRACT

This series of experiments evaluates the performance of pressure-pulse transducers in determining distances of installed gages from small H. E. detonations by measuring seismic wave travel times. Because of the superiority of the system time resolution as compared with conventional geophysical exploration equipment, improved accuracy was anticipated as well as an opportunity to dry-run the installed system in the operational environment. Also, a requirement for seismic velocity measurements in situ was fulfilled.

Travel time measurements used "satellite"-hole gage placements, 5-pound C-4 detonations near the planned location of the device in the device hole, and operational diagnostic facilities. The results verified the original premise of the suitability of Plowshare instrumentation to determine with superior accuracy installed gage distances from the small H. E. detonations. Agreement of within 1% between surveyed distances and calculated distances was obtained for the three gage locations reporting. Seismic velocities obtained fell between 3825 and 3875 feet per second. Also, the experiment demonstrated the integrity of the Plowshare instrumentation system as installed.

PREFACE

Seismic velocity measurements planned for Project Sedan were contingent on the feasibility of certain steps in the experiment. Transducer performance at low energy input was unknown. The capability of the device-hole casing to withstand small high-explosive detonations was also unknown. No guarantee existed that sufficient time could be scheduled to conduct the measurements during the appropriate period. Accordingly, certain preliminaries were completed to demonstrate the feasibility of this experiment and to provide backup in the event that this experiment could not be completed.

Required preliminaries, described herein, included:

1. Transducer performance tests using low-energy buried detonations.

2. Test detonations in typical device-hole casing.

3. Preshot velocity survey at the Sedan site by United ElectroDynamics, Inc.

Each of the preliminaries and the culminating experiment on Sedan are given separate chapters in this report.

CONTENTS

CONTENTS (Continued)

CHAPTER 1

TRANSDUCER PERFORMANCE TESTS USING LOW-ENERGY BURIED DETONATIONS

The piezoelectric crystal transducers used in these tests were similar to those used for stress history measurements on Project Sedan. (Reference 1.)

1.1 INTRODUCTION

The performance of Mark V ceramic pin assemblies and tourmaline transducer assemblies was determined on 7 June 1962 at Site 300, Livermore, for buried charges of 1 to 5 pounds at ranges of 100 and 200 feet. This determination was a necessary preliminary to the use of this type of instrumentation on Project Sedan. The tests were conducted in order to verify that satisfactory performance at these yields and ranges would prevail on Project Sedan for proposed seismic travel-time measurements.

1.11 Equipment. Tables 1.1A and 1.1B present principal features of the instrumentation.

1.12 Physical Arrangements. Figure 1.1 shows the arrangement of shot and gage holes.

1.2 PROCEDURE

Instruments were placed at the bottoms of uncased instrument holes and covered with 2-3 feet of earth, tamped and settled with about one gallon of water. Four dual-trace oscilloscopes were used to display voltage-time histories from the transducers. Prior to each shot, the explosive, C-4, was loaded at the bottom of the shot-hole casing (8-inch corrugated metal pipe) and tamped with about 5 feet of earth. Firing from a local CDU driven from the

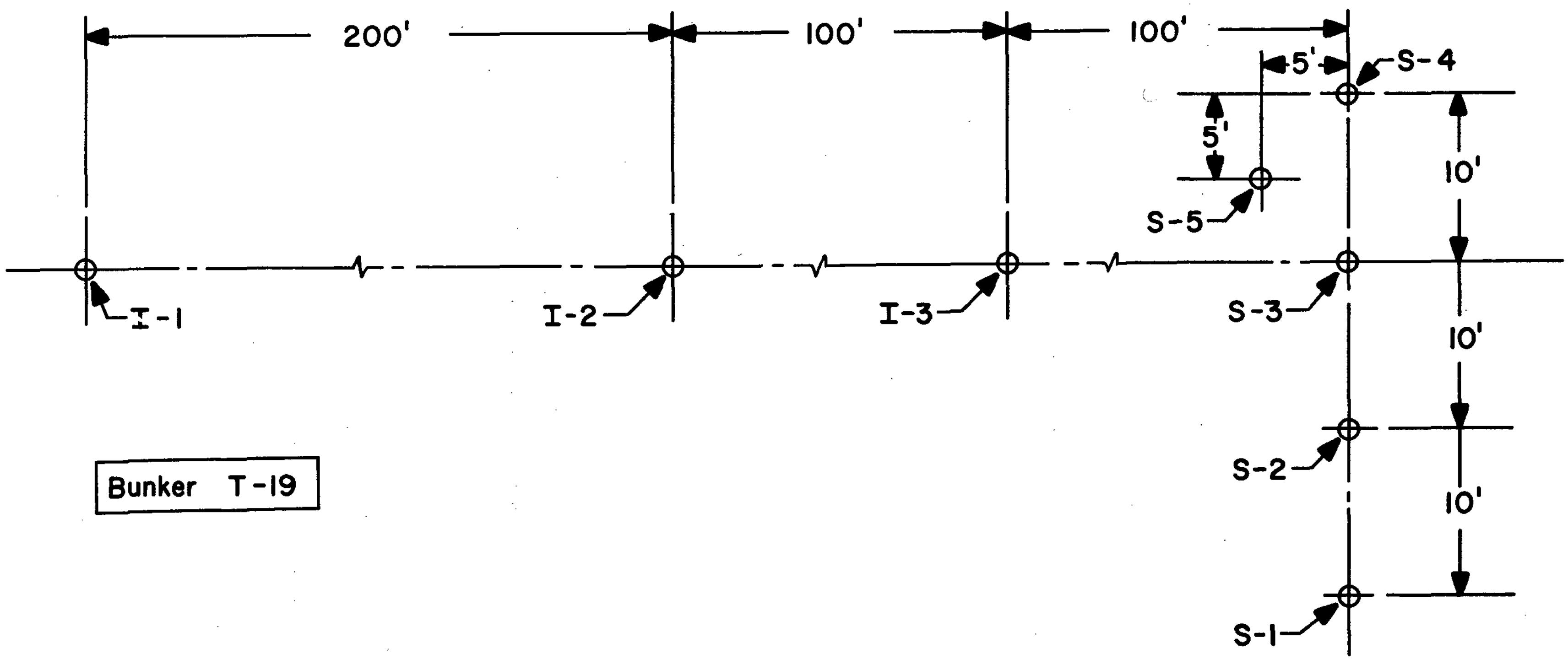


Figure 1.1 Physical arrangement, transducer performance tests. Holes I-1 through I-3 (instrument holes) and S-1 through S-4 (shot holes) are 9 feet deep. Shot hole S-5 is 5 feet deep.

bunker also triggered the oscilloscopes. Sensitivity was 5 millivolts per centimeter throughout.

TABLE 1.1A INSTRUMENTATION FOR TRANSDUCER PERFORMANCE TESTS

Shot	C-4 Explosive Weight	Shot Hole	Instrumentation and Range Hole I-1	Hole I-2	Hole I-3
	pounds				
SEW-1	5	S-1	Endevco[a]	Tour.[b] PZT[c]	Tour. PZT
SEW-2	5	S-2	-	-	Endevco Tour. PZT
SEW-3	5	S-3	-	Tour. PZT	Tour. PZT
SEW-4	1	S-4	-	Tour. PZT	Tour. PZT
SEW-5	3	S-5	-	Tour. PZT	Tour. PZT

[a] Endevco – Endevco Corporation, accelerometer type 2218.
[b] Tour. – tourmaline transducer assembly. See Reference 1.
[c] PZT – Mark V ceramic pin assembly. See reference 1.

TABLE 1.1B SYSTEM CAPACITANCE AS INSTALLED FOR TRANSDUCER PERFORMANCE TESTS

Location	Transduçer Tour.	PZT	Endevco
	pF	pF	pF
Hole I-2	7.9	8.05	-
Hole I-3	10.7	11.40	15.05

1.3 RESULTS

Figure 1.2 presents photographic data obtained. Shot 1 did not result in appreciable amplitudes. No explanation is known for this effect. Shots 2 and 3 confirmed that both types of Plowshare transducers would give adequate signals for ranges less than 100 feet and that the tourmaline assembly was preferable.

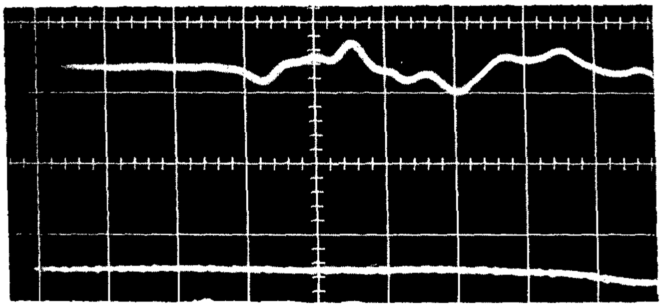
The Endevco accelerometer was not used after Shot 2 since the results at 100 feet were not considered adequate. Shots 4 and 5 confirmed that 5 pounds was an appropriate minimum charge weight for ranges up to 100 feet.

It is believed that first arrivals have been refracted through the underlying sandstone formation which at this location is probably less than 10 feet below both shot and instrument locations. This may account for the tendency toward lower amplitudes of first arrivals.

1.4 CONCLUSIONS

Results obtained are necessarily applicable only to the prevailing conditions of this location and arrangement. Extrapolation to other locations is possible through careful adjustment for differing conditions.

On the basis of this experiment, pre-Sedan velocity determinations with this type of instrumentation appear feasible. For comparable charges and ranges, signal level at NTS should improve over Site 300 because of better medium, better casing-to-medium coupling, and better medium-to-transducer coupling. The larger casing diameter at NTS may degrade somewhat the energy input to the casing.



200 msec sweep,
zero delay

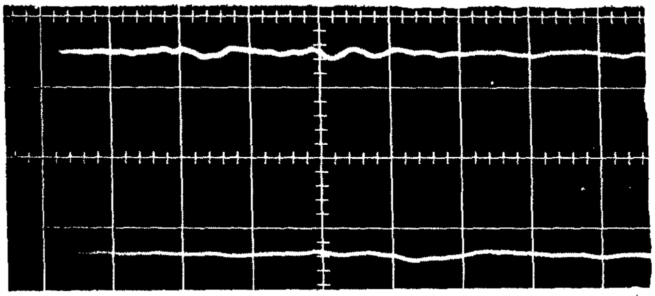
Run 2, 5 lb
Tourmaline, 100 ft

50 msec sweep,
20 msec delay

500 msec sweep,
zero delay

Run 3, 5 lb
Tourmaline, 100 ft

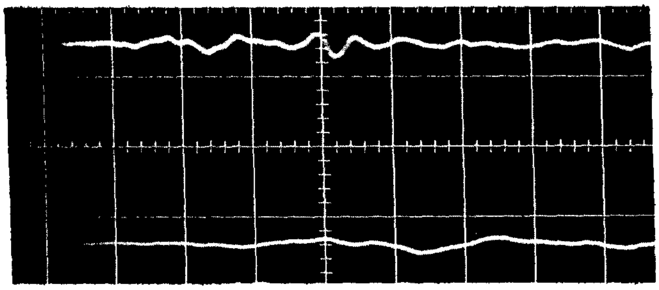
200 msec sweep,
zero delay



500 msec sweep,
zero delay

Run 4, 1 lb
Tourmaline, 100 ft

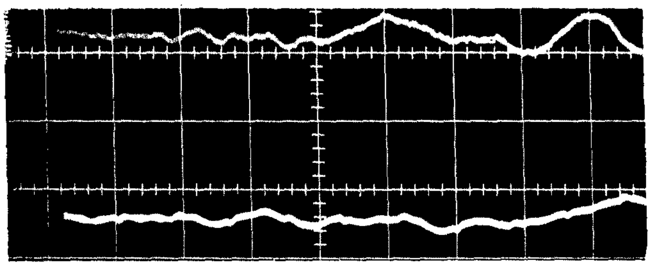
200 msec sweep,
zero delay



500 msec sweep,
zero delay

Run 5, 3 lb
Tourmaline, 100 ft

200 msec sweep,
zero delay

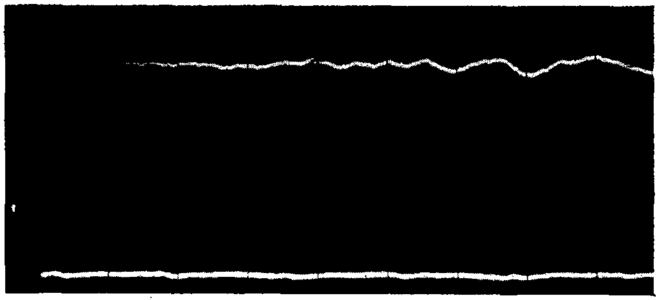


200 msec sweep,
zero delay

Run 2, 5 lb
Endevco, 100 ft

100 msec sweep,
20 msec delay

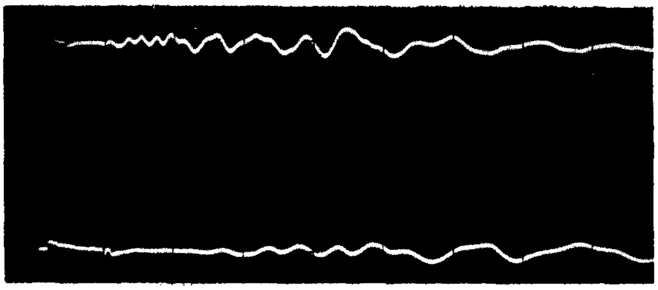
Figure 1.2 Voltage-time histories, transducer performance tests.



200 msec sweep,
zero delay

Run 2, 5 lb
Ceramic pin, 100 ft

50 msec sweep,
20 msec delay



500 msec sweep,
zero delay

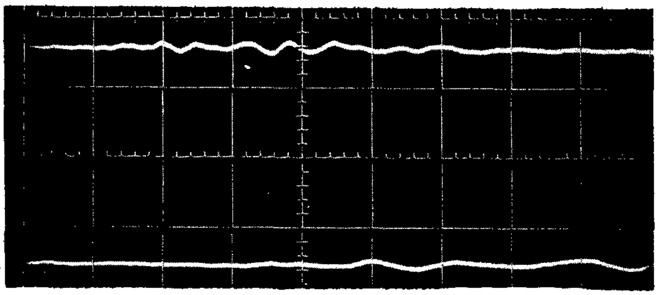
Run 3, 5 lb
Ceramic pin, 100 ft

200 msec sweep,
zero delay

500 msec sweep,
zero delay

Run 4, 1 lb
Ceramic pin, 100 ft

200 msec sweep,
zero delay

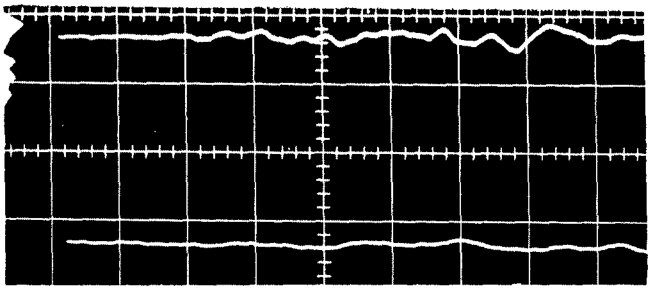


500 msec sweep,
zero delay

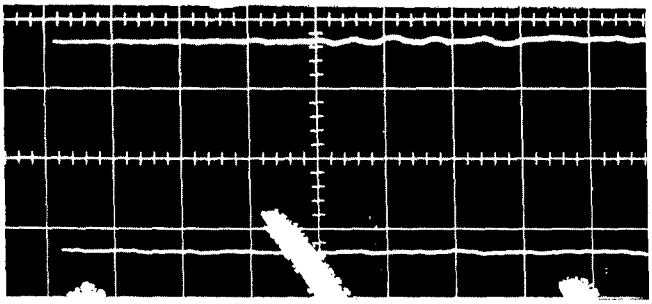
Run 5, 3 lb
Ceramic pin, 100 ft

200 msec sweep,
zero delay

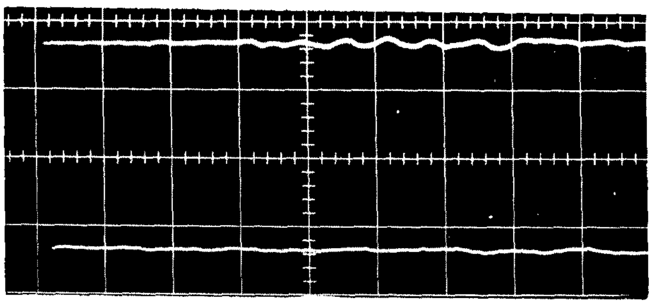
Figure 1.2 (Continued) Voltage-time histories, transducer performance tests.



Run 3, 5 lb

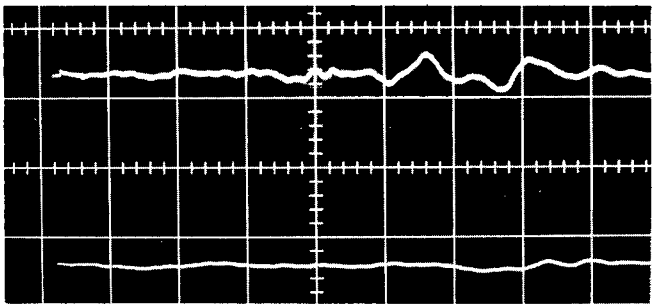


Run 4, 1 lb

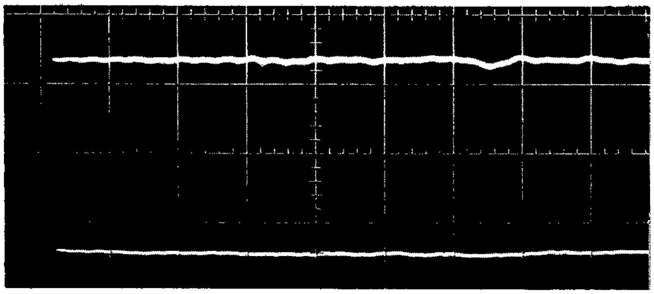


Run 5, 3 lb

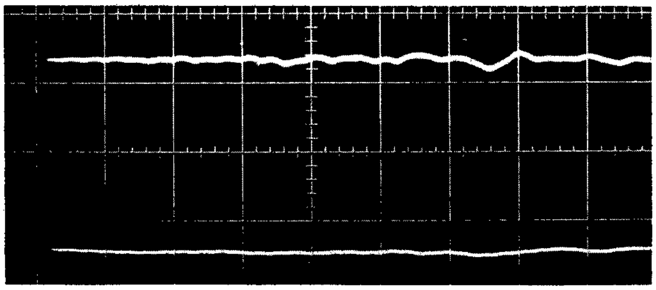
Figure 1.2 (Continued) Voltage-time histories, transducer performance tests. Upper traces, 500 msec sweep and zero delay; lower traces, 200 msec sweep and 50 msec delay. Tourmaline, 200 feet.



Run 3, 5 lb



Run 4, 1 lb



Run 5, 3 lb

Figure 1.2 (Continued) Voltage-time histories, transducer performance tests. Upper traces, 500 msec sweep and zero delay; lower traces, 200 msec sweep and 50 msec delay. Ceramic pin, 200 feet.

CHAPTER 2

TEST DETONATIONS IN TYPICAL DEVICE-HOLE CASING

Only limited experience exists concerning the survival of drill-hole casing subjected to internal detonations. Accordingly, approval to detonate units of several pounds of high explosive at depth in the Sedan device hole, cased with 3/4-inch-wall, 36-inch-i.d. steel casing, was withheld pending a demonstration of the performance of typical casing subjected to internal detonations.

2.1 INTRODUCTION

On 26 June 1962, a series of charges were detonated in typical 36-inch-i.d. casing contained in a drilled hole in Area 9, NTS. The results of these tests established the feasibility of similar detonations in the Sedan device hole.

2.11 Physical Arrangements. The physical arrangement consisted of an 11-foot length of 36-inch-i.d. (3/4-inch-wall) casing placed vertically in a drilled hole. The annulus around the casing was filled to ground level with grout and a 6-inch grout plug was poured at the bottom of the casing and retained by a 1/4-inch steel plate welded to the lower end of the casing.

The casing extended approximately 14 inches above ground and grout surface. The firing horizon was 5 feet 4 inches below the top of the casing, except for the last shot.

2.12 Explosive Assemblies. Explosive charges of C-4 plastic were prefabricated in 2-1/2- and 5-pound quantities and contained in plastic poultry bags. For any shot, an appropriate number of charges were taped together and mounted on a wood frame. One charge carried a detonator and firing cable, the cable being secured to the wood frame and used to support the assembly in the hole.

Three loops of No. 8 galvanized iron were attached to the wood frame to provide self-centering contact with the casing.

2.2 PROCEDURE

Shots were assembled in sequence at the casing head from a local magazette. The assembly was lowered to the required depth and suspended by the firing cable from a strut across the casing top. Firing was from a local vantage point with a high-voltage CD unit. After each shot, the casing was gaged top to bottom with a circular gage to estimate dimensional changes. Photographs were taken of the inside and outside of the casing between shots. The firing schedule used is given in Table 2.1.

TABLE 2.1 FIRING SCHEDULE, CASING TESTS

Shot Number	C-4 Explosive Weight
	pounds
1	5
2	7-1/2
3	10
4	15
5	20
6	15 (at bottom of hole)

2.3 RESULTS

No dimensional changes were noted through Shot 3 by the gaging procedure. After Shot 4 (15 pounds), a diametral change of about 1/2 inch was noted in the NE-SW direction, affecting a vertical length of about 6 inches. After Shot 5 (20 pounds), this change

had increased to about 1 inch total. No decrease in diameter was noted at any time anywhere in the casing.

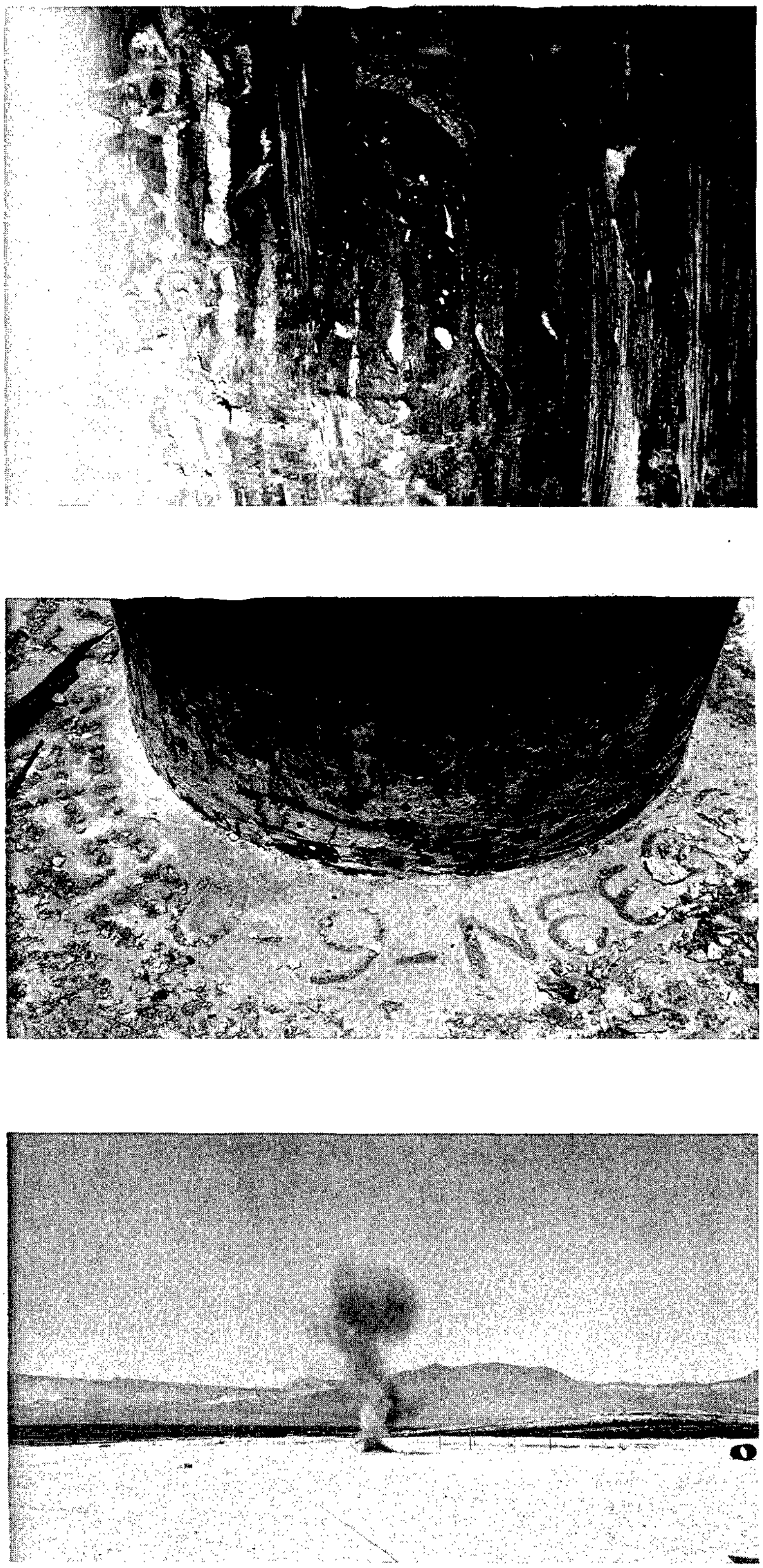
Figure 2.1 shows results of certain shots. Shots 4 and 5 (15 and 20 pounds) produced a small amount of pocking of the inner surface of the casing. A detailed examination of the casing interior for dimensional variation was made after Shot 6. Results shown in Figure 2.2 are in substantial agreement with results of the gaging procedure.

2.4 CONCLUSIONS AND RECOMMENDATIONS

Results of these tests indicate that small charges can be detonated in this type of casing and support without alteration to the casing that would interfere with containment or handling of the device packages. Some stretching of the casing was noted from charges above 10 pounds, and the supporting grout around the casing showed a small separation from the casing. These alterations would not be expected to interfere with casing use. No cracks, openings, or discontinuities were caused by even the largest charge (20 pounds), nor was there any reduction in diameter.

The following recommendations, applicable to this type of casing and support, were made:

1. Maximum weight of any single charge should be 10 pounds, C-4 equivalent.
2. Clearance between charge and wall should be a minimum of 12 inches.
3. Charge location should be at least one diameter from any circumferential weld.
4. At any one horizon, the total weight of all charges fired should not exceed 60 pounds, C-4 equivalent.

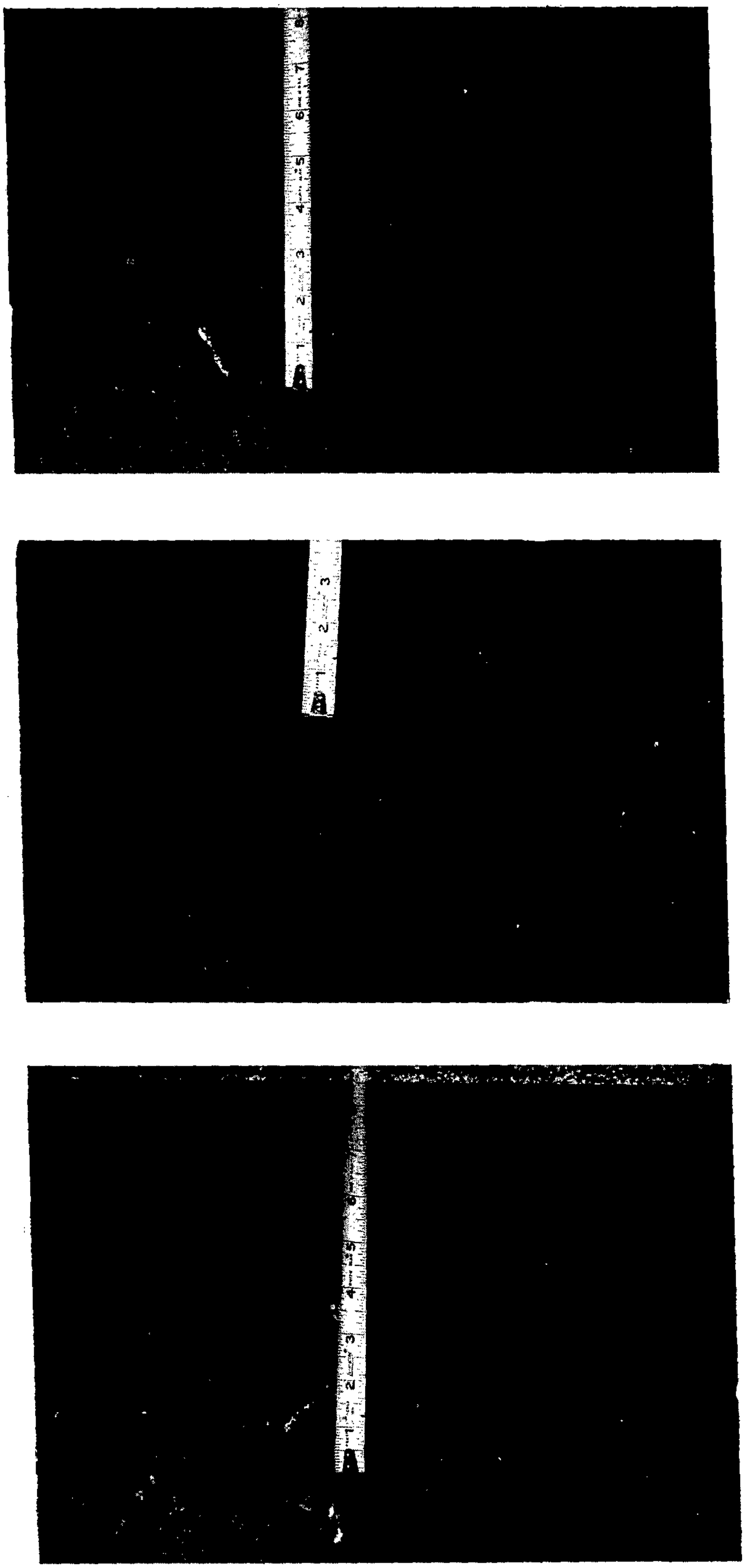


(a)

(b)

(c)

Fig. 2.1 (a) Preshot close-up of internal surface of casing. (b) External view showing preshot bond between grout and casing. (c) Typical effects of detonation as seen at surface.



(d)

(e)

(f)

Figure 2.1 (Continued) Close-ups of internal surface of casing (d) after Shot 1, 5 lb, (e) after Shot 3, 10 lb, (f) after Shot 4, 15 lb.

(g)

(h)

Figure 2.1 (Continued) (g) Close-up of internal surface of casing after Shot 6, 15 lb. (h) External view after shot showing bond between grout and casing.

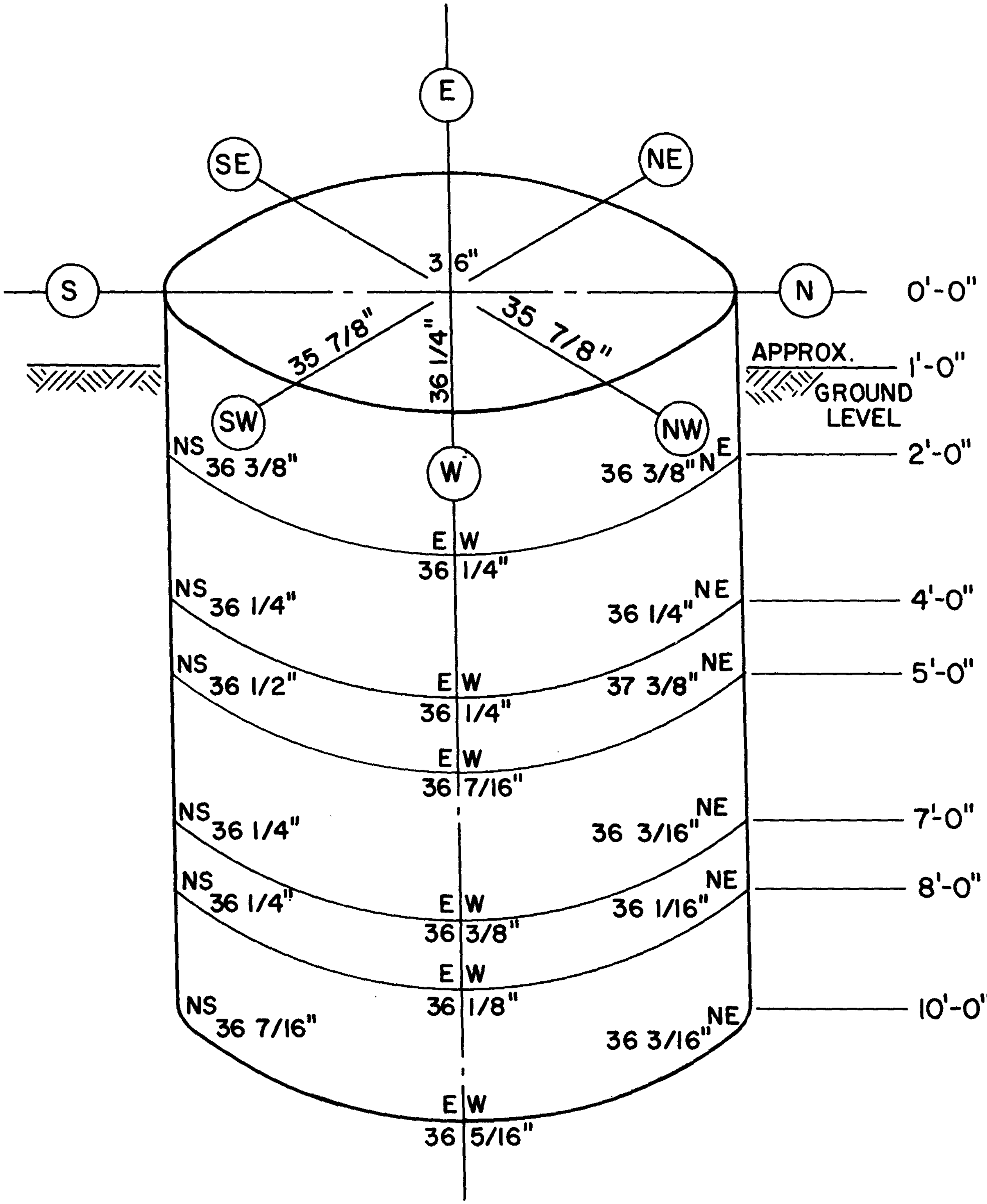


Figure 2.2 Measurements of 36-inch-i.d. casing after test detonations.

CHAPTER 3

PRESHOT VELOCITY SURVEY

The preshot velocity survey was conducted by United Electro-Dynamics, Inc. (UED), using United Geophysical Corporation recording instruments, under Reynolds Electrical and Engineering Company Purchase Order 10867B1.

3.1 INTRODUCTION

Distances were desired from the working point of the Sedan device to certain gages installed in satellite hole U10H-1. Also, the seismic velocity near the gage and shot horizons was desired. The velocity survey by UED provided a basis for calculating these data within the capability of conventional exploration geophysics equipment. The use of the UED technique provided scheduling flexibility necessary to guarantee that the required data would be obtained.

The final report submitted by UED is reproduced as Appendix A. It includes detailed procedure and results.

3.2 COMPARISON OF RESULTS

The results of the velocity survey by UED are compared with measurements by others.

3.21 Longitudinal Velocity. Longitudinal velocities reported by UED at this location range between 2977 and 3136 feet per second. Refraction and vertical velocity surveys were conducted in 1951 in this area at comparable depths (Reference 2).

The vertical velocity surveys in this area indicate velocities of approximately 3000 feet per second from the surface to a depth of 150 feet, approximately 3900 feet per second from 150 to 450 feet depth, and more than 5000 feet per second below 450 feet depth.

Horizontal velocities indicated by refraction surveys are random in many cases and it is assumed they represent discontinuous beds. Surface layer velocities range between 2500 and 3000 feet per second. Below the surface layer, horizontal velocities range between 3500 and 5200 feet per second. The horizontal velocities given are in general agreement with seismic exploration by the USGS (Reference 3).

3.22 Shot-Detector Distances. Sperry-Sun well surveys were made on both U10H and U10H-1 drill holes. Surface surveys by Holmes and Narver connected the two well surveys. Based on these surveys, space coordinates were obtained for the hole intersection at the several horizons of interest. From these coordinates, connecting distances were computed corresponding to the various points determining shot-detector distances listed by UED. Table 3.1 presents a comparison of the results obtained by the two methods.

TABLE 3.1 COMPARISON OF SHOT-DETECTOR DISTANCES OBTAINED FROM UED VELOCITY SURVEY AND FROM DRILL HOLE SURVEYS

Distances are from wall of shot hole U10H to center of detector hole U10H-1.

Shot Depth	Detector depth	Distance from UED Velocity Survey	Distance from Drill Hole Survey
feet	feet	feet	feet
630	630	26.2	23.3
630	605	36.0	34.2
630	590	49.0	46.3
630	555	80.1	78.5
630	535	97.9	97.8
630	515	116.4	117.3
515	515	25.3	24.8
515	535	32.3	31.9
515	590	79.2	79.0
515	605	93.3	93.4
410	410	29.3	26.2
410	455	53.6	52.1
410	485	81.3	79.4
410	515	107.2	108.2
410	535	126.6	127.7
410	555	147.2	147.3

CHAPTER 4

PRESHOT TRAVEL-TIME MEASUREMENTS WITH INSTALLED STRESS-HISTORY TRANSDUCERS

Transducers (see Reference 1) installed in Hole U10H-1 for stress history measurements were used to obtain travel times of seismic energy from small H. E. charges detonated in the device hole U10H near the level where the device would be placed.

4.1 INTRODUCTION

The stress history program (see Reference 1) required accurate knowledge of the *in situ* longitudinal velocity and of the distances between the device working point and installed gages. It was believed that use of stress history instrumentation coupled with low energy detonations at the shot horizon would provide the required information with an accuracy not permitted by other available means.

The feasibility of using stress history transducers to receive seismic signals from low energy detonations was established as reported in Chapter 1. Approval was obtained to detonate small charges in the device hole casing at the shot horizon based on the results of tests reported in Chapter 2.

Over the range of interest, depth 485 to 630 feet, the drill hole survey showed a lateral drift of the gage hole, U10H-1, of about 0.25 foot, with less than 0.1 foot drift between any two gage points. Under these circumstances, the gage hole can be assumed vertical and straight. Over the range of interest, deviations of the seismic velocity from a characteristic or mean value will cause a proportional error in calculated shot-gage distances, assuming small deviations in velocity. If the assumption is valid, accurate shot-gage distances can be obtained using only measured travel times and known differences in depth between

shot point and gages. The assumption will be verified by concurrence of velocity values for three or more shot-gage distances.

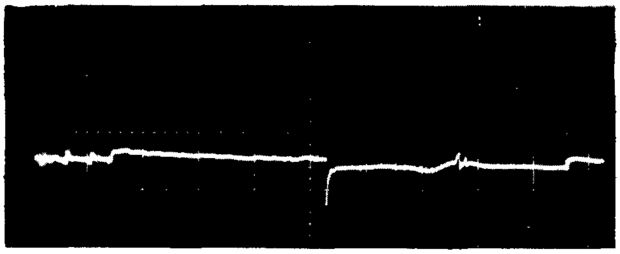
On 28 June 1962 approval was given to proceed, with the restriction that the work had to be completed in 16 hours to allow resumption of scheduled activities. This eliminated dry runs, from lack of time, and resulted in the usual difficulties attendant to an unrehearsed experiment.

4.2 PROCEDURE

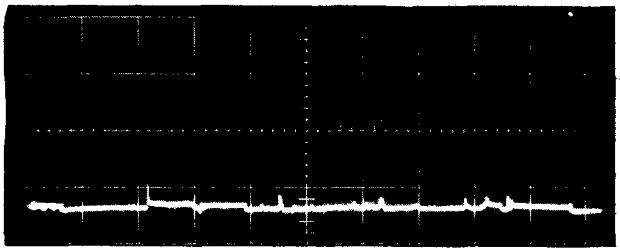
Charge assemblies as described in Chapter 2 were suspended at the shot horizon from a 1/4-inch steel cable. A transducer mounted on the charge for a trigger was connected to provide a system identical to the time-of-arrival gages. Three charges were detonated in the device hole, using #12 blasting caps fired from a surface vantage point with a low-voltage CD unit. Initially, oscilloscope gains, sweep times and delays were set to provide maximum signal and record duration. The first charge fired gave no trigger. After the first recorded shot, which was the second charge fired, time scales were expanded for greater accuracy. Also, gains were reduced to contain the signal level, which overranged some of the first records.

4.3 RESULTS

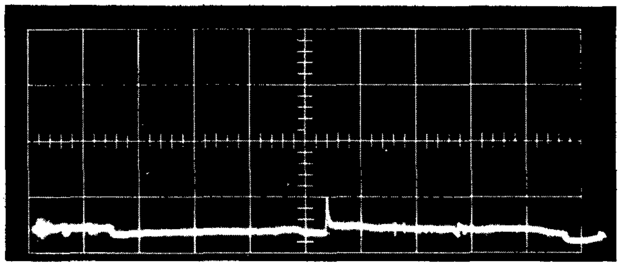
The second charge fired, Run 1, triggered and recorded on 5 of 9 channels from gages in the satellite hole, U10H-1. The third charge fired, Run 2, recorded on all channels; however, the records were noise-ridden and not usable. The records from Run 1, shown in Figure 4.1, approach expected registration. Shot-gage distances, under the original premise, were to be completely determined using only two sources of data: (1) travel times, and (2) gage and shot depths.



Gage 1, Scope 1B, depth 605 ft
Zero delay
Vertical, 50 mV/cm
Horizontal, 2 msec/cm

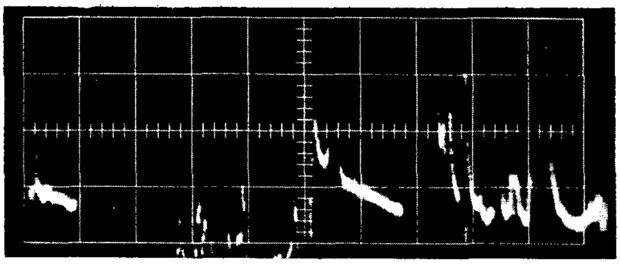


Gage 1, Scope 2, depth 605 ft
Zero delay
Vertical, 100 mV/cm
Horizontal, 5 msec/cm



Gage 2, Scope 3, depth 590 ft
Zero delay
Vertical, 50 mV/cm
Horizontal, 2 msec/cm

Gage 3, Scope 4, depth 555 ft
15 msec delay
Vertical, 100 mV/cm
Horizontal, 2 msec/cm



Gage 6, Scope 8, depth 485 ft
15 msec delay
Vertical, 5 mV/cm
Horizontal, 5 msec/cm

Figure 4.1 Voltage-time histories, Run 1. Preshot travel time measurements.

4.31 Travel Times. Both recordings agree for the travel times to Gage 1. The record from Gage 2, although well defined, was discarded after comparison with the records from Gage 1. The records from Gages 3 and 6, although noise-ridden, each contain excursions of sufficient duration to be considered. Table 4.1 presents travel times selected.

TABLE 4.1 SELECTED TRAVEL TIMES FROM RUN 1
Shot depth 631.6 feet.

Gage Number	Gage Depth	Travel Time
	feet	msec
1	605	10.5
3	555	22.0
6	485	40.0

4.32 Gage and Shot Horizon Depths. The shot horizon depth given in Table 4.1 is measured to the center of the charge. The gage depths given in Table 4.1 are nominal depths from the instructions issued for placing the gages.

4.33 Mean Velocity Across Shot-Gage Distances. It is assumed that the gage locations lie along the vertical and that the arrivals traveled the casing radius (1.5 feet) in air at 1120 feet per second and the remaining distance at a velocity constant for the several paths. Using only the information in Table 4.1, velocities obtained ranged from 3825 to 3875 feet per second with a mean velocity across the shot-gage distance of 3845 feet per second. The agreement between velocities obtained for the several gage locations verifies that correct signal characteristics were selected in determining arrival times. The records also verify that alternate paths existed for transmission of energy from shot to gage.

4.34 Comparison of Shot-Gage Distances Calculated from Travel Times and from Drill Hole Surveys. In evaluating this comparison, shown in Table 4.2, at least two conditions must be considered: (1) physical gage locations do not necessarily coincide with drill-hole survey points; and (2) accuracy of the drill-hole survey measurements is unknown.

TABLE 4.2 COMPARISON OF SHOT-GAGE DISTANCES CALCULATED FROM TRAVEL TIMES AND FROM DRILL HOLE SURVEYS

Shot depth 631.6 feet.

Gage Number	Gage Depth	Distance from Travel Time	Distance from Drill Hole Survey
	feet	feet	feet
1	605	36.6	36.4
3	555	79.8	80.6
6	485	148.2	148.7

The shot-gage distances calculated from travel times were obtained as products of velocity and travel time associated with the path in alluvium for each gage. This distance was then corrected for the casing radius to obtain shot-gage distance.

4.4 CONCLUSIONS

1) Charges as large as 5 lb can be detonated without adverse effect in a Sedan-type environment.

2) Low energy detonations are useful in establishing the preshot integrity of this type of diagnostic system.

3) The data recovered from this experiment is sufficient for determination of shot-gage distances for those gages reporting.

4) Seismic velocities obtained from this experiment are consistent within ±1 percent. Agreement between shot-gage distances arrived at by this method and by survey methods is within 1 percent.

5) Shot points at additional levels are required for adequately covering gage spans greater than 150 feet.

REFERENCES

1. F. Holzer; "Yield Measurements"; Project Sedan, PNE-232; Unclassified.

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(APPENDIX A)

FINAL REPORT
OF
VELOCITY SURVEY
U-10h AREA - N.T.S.

For

LAWRENCE RADIATION LABORATORY

By

UNITED ELECTRODYNAMICS, INC.
and
UNITED GEOPHYSICAL CORPORATION
PASADENA, CALIFORNIA

AUGUST, 1962

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INTRODUCTION

A velocity survey was conducted on June 21, 22, and 23, 1962 in Area 10 at the Nevada Test Site for Lawrence Radiation Laboratory. The survey was conducted by United ElectroDynamics, Inc. using United Geophysical Corporation recording instruments under Reynolds Electrical and Engineering Company Purchase Order 10867B1.

The objectives of the survey were to determine the distances and compressional seismic velocity between holes U10h and U10h-1. The zone of interest was between 410 and 630 feet below the surface.

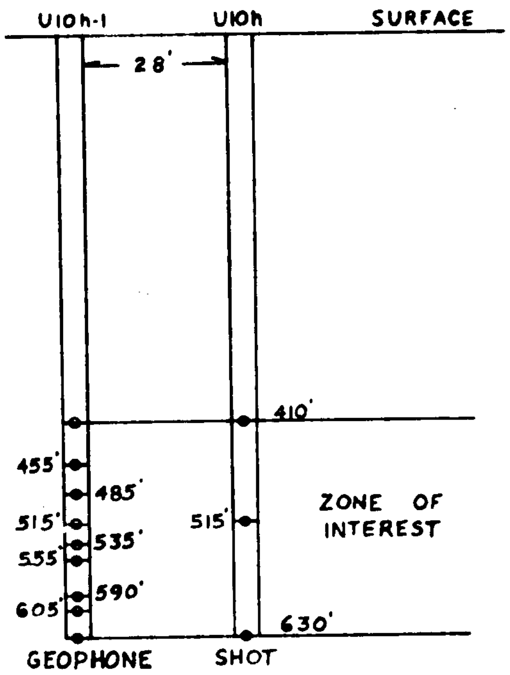


Figure 1

RESULTS

The average compressional-wave seismic-velocity for the zone of interest (depth 410 to 630 feet below the surface) was determined to be 3,080 ft/sec. Computed velocities deviated from the 3,080 ft/sec average value by $\pm$ 35 ft/sec. Several shots were recorded at each instrument location to minimize the error in establishing arrival times. The average velocity was computed by using observed travel times for two sides of a right triangle, the third side of which was known. (See Figure 2).

Hole to hole distances for various paths were determined by multiplying the velocity (3,080 ft/sec) by the observed travel times. These distances are considered to be generally accurate within plus or minus one foot. Because of the geometry, the potential error increases as the angle with the horizontal from the shot-to-geophone increases.

Some difficulty was caused by "precursory" wave arrivals representing energy having traveled some distance along the high velocity casing of shot hole U10h before "crossing over" to adjacent instrument hole U10h-1. It was necessary in some cases to estimate arrival times for direct "rock paths", which were superimposed on the earlier arriving "steel casing waves". It would be helpful in future surveys to extend the depth of the instrument holes, if possible, some 200 feet below the elevation of the bottom of casing in the shot hole.

DATA REDUCTION AND PRESENTATION

A preliminary investigation of the first energy arrivals on the seismograms recorded from the shots at 630 feet depth indicated travel times shorter than expected with increase in radial distance from shot to geophone. A time-distance graph shows a curve with apparent velocity increasing with increase in distance. The apparent velocities ranged from approximately 3,100 feet per second to 9,400 feet per second. This indicated the presence of high velocity material (steel casing) in the total travel path.

The time-distance graphs of the first arrival times from the shots at 410 and 515 feet depths reflected an increase in apparent velocity with increased distance. These recordings were to geophones at or below the shot depth. This likewise indicated the presence of high speed casing travel.

A plot of first arrival times versus elevation of the geophone indicated a constant interval velocity of approximately 14,600 feet per second which is within the range of expected casing velocities.

Valid secondary energy arrivals identifiable on at least 50 per cent of the records were picked, timed, and corrected to the nearest 0.0001 second and are considered to be generally accurate within plus or minus 0.0003 second.

The following corrections were applied to each observed travel

time, as applicable.

1. A 0.0005 second detonation delay is discussed under "Blaster Time-Delay" in the Field Procedure section.

2. The distance from the centered shots to the hole wall was 1.5 feet. At a seismic velocity in air of 1,090 feet per second, this distance requires a travel time of 0.0014 seconds. For the same 1.5 feet radial distance the travel time in water is 0.0003 seconds.

Shots at the 630 feet depth were detonated in water. Shots at the 410 and 515 feet depths were detonated in air.

Since the above corrections result in computed measurements between the U10h hole wall and the center of U10h-1, this 1.5 feet radial distance has been added to all computed horizontal distances shown in Figure 6.

Figure 2 illustrates the formula used for determining the compressional wave seismic velocity. Tables 1, 2, and 3 list the data used for determining the velocity for each of the 13 triangles. Figures 3, 4, and 5 show the graphs of the time squared versus the vertical distance squared. The indicated velocity from these graphs is 3,080 feet per second. The arithmetic average of the individually computed velocities is 3,080 feet per second. Tables 4, 5, and 6 show the computed distances between hole wall U10h and center of hole U10h-1 within the zone of interest.

FIELD PROCEDURES

Instruments:

United Geophysical Corporation portable 1-36 amplifiers and camera (type 5-24) with 25 mirror galvanometers (natural frequency 500 c.p.s.) were used on this survey. Timing lines were produced every 0.001 second on the seismograms. High amplitude recording appears on traces 1, 2, and 3 and low amplitude recording on traces 4, 5, and 6. Recording was done through an M-1-4 filter with low frequency cut off at 27 c.p.s. and high frequency cut off at 100 c.p.s.

Three ElectroTechnical Laboratories transducers were used, mounted orthogonally in a single case. The geophones (model EVS-2) have a natural frequency of 30 cycles per second.

An S.I.E. blaster (type SCD 2000BA operated at 1000 volts) was used to detonate the du Pont SSS caps.

Geophone Emplacement:

The desired depths for the geophone were measured with a surveyor's chain and were indicated on the geophone lead with a tape marker. Because of the thick drilling mud in hole U10h-1, approximately 15 pounds of weight were attached to the instrument case to ensure reaching proper depth.

The polarity of the system was checked by tap tests. It was established that the galvanometer trace deflected upward on the seismogram with upward motion of the geophone case.

Shot Emplacement:

The firing line with the centering device attached was measured with a surveyor's chain. An electrically powered winch was used for lowering and raising the cable and the centering device between shots.

Blaster Time-Delay:

Due to the appreciable length and resistance of the firing line, there was a time-delay between the time-break from the blaster and the actual detonation of the cap. To determine this time-delay, a separate wire was wrapped around the cap and connected in a d.c. circuit to the galvanometer. When the cap detonated, the d.c. circuit was broken, causing a deflection of the galvanometer. From three such tests, a 0.0005 second constant time-delay was determined which was applied to the time reference on each seismogram.

Generation of Compressional Waves:

Compressional waves were generated by detonating a cap and booster (maximum charge cap and two boosters) in hole U10h. Multiple shots were recorded at each geophone location. The three shooting depths were 410, 515, and 630 feet below the surface.

CONCLUSIONS AND RECOMMENDATIONS

The velocity and the distances determined by this survey are considered to be reliable for the zone investigated, despite certain sources of potential error as discussed under "Data Reduction and Presentation". The computed distances between U10h and U10h-1 are considered generally accurate within plus or minus one foot.

The technical reliability of these measurements could probably be improved. However, the factors which must be considered are those of safety, time and coordination of operations between agencies.

Suggestions on areas which would contribute to improvement are as follows:

1. All charges should be detonated under the same conditions (preferably in fluid).
2. For horizontal distance determinations the angle with the horizontal from the shot to the instrument should be held to a reasonable maximum, probably within the range of 60 to 65 degrees. Figure 7 shows graphically the diminishing hole location accuracy accompanying increase in this angle without horizontal check shots, assuming a seismic velocity of 4,000 feet per second.
3. When possible the instrument hole should be drilled deeper than the bottom of the shot hole casing by at least 100 feet,

preferably 200 feet. This should establish a more definite velocity for the material in question by elimination of the casing-transmitted seismic wave which tends to interfere with identification of the direct path arrival times on the seismogram.

TABLE I

Computation for compressional wave seismic velocity between U10h and U10h-1 determined from shots at depth 630 ft. in U10h. (See Figure 2)

Geophone Depth U10h-1	Distance (feet) X	Time (seconds) t_1	t_2	Velocity (ft/sec)
630	0	0.0085		
605	25		0.0117	3109
590	40		0.0159	2977
555	75		0.0260	3052
535	95		0.0318	3100
515	115		0.0378	3122
	Average Velocity			3072

TABLE II

Computation for compressional wave seismic velocity between U10h and U10h-1 determined from shots at depth 515 feet in U10h. (See Figure 2)

Geophone Depth U10h-1	Distance (feet) X	Time (seconds) t_1	t_2	Velocity (ft/sec)
515	0	0.0082		
535	20		0.0105	3050
590	75		0.0257	3079
605	90		0.0303	3085
	Average Velocity			3071

TABLE III

Computation for compressional wave seismic velocity between U10h and U10h-1 determined from shots at depth 410 feet in U10h. (See Figure 2)

Geophone Depth U10h-1	Distance (feet) X	Time (seconds) t_1	t_2	Velocity (ft/sec)
410	0	0.0095		
455	45		0.0174	3087
485	75		0.0264	3045
515	105		0.0348	3136
535	125		0.0411	3126
555	145		0.0478	3095
	Average Velocity			3098

TABLE IV

Computed distance between hole wall U10h and center of hole U10h-1 determined from shots at depth 630 feet in U10h.

Geophone Depth	Time (seconds)	Shot-Detector Distance (feet)
630	0.0085	26.2
605	0.0117	36.0
590	0.0159	49.0
555	0.0260	80.1
535	0.0318	97.9
515	0.0378	116.4

Note: Using velocity of 3,080 feet per second.

TABLE V

Computed distances between hole wall U10h and center of hole U10h-1 determined from shots at depth 515 feet in U10h.

Geophone Depth	Time (seconds)	Shot-Detector Distance (feet)
515	0.0082	25.3
535	0.0105	32.3
590	0.0257	79.2
605	0.0303	93.3

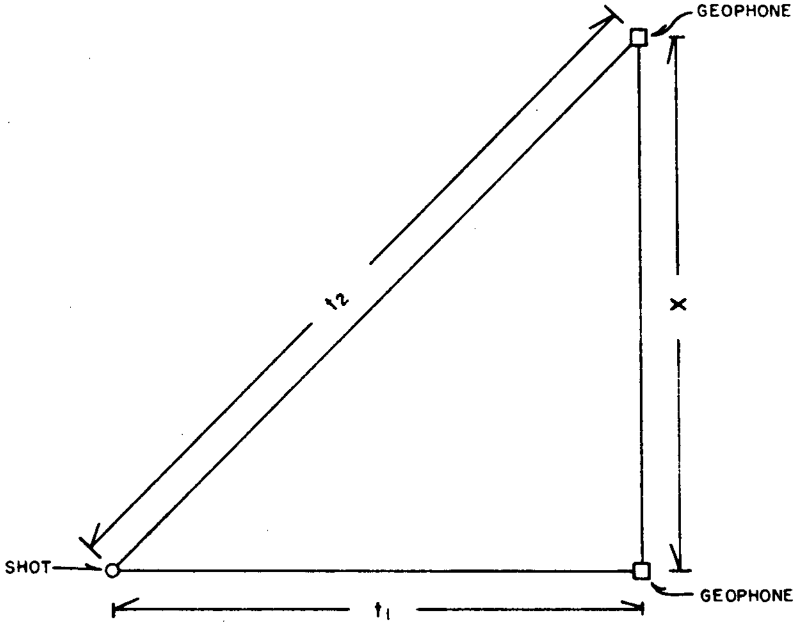
Note: Using velocity of 3,080 feet per second.

TABLE VI

Computed distance between hole wall U10h and center of hole U10h-1 determined from shots at depth 410 feet in U10h.

Geophone Depth	Time (seconds)	Shot-Detector Distance (feet)
410	0.0095	29.3
455	0.0174	53.6
485	0.0264	81.3
515	0.0348	107.2
535	0.0411	126.6
555	0.0478	147.2

Note: Using velocity of 3,080 feet per second.



1. t_1 and t_2 equal direct observed travel time.

2. X equal vertical distance between geophone positions.

3. PYTHAGOREAN THEOREM:

$$(Vt_2)^2 = X^2 + (Vt_1)^2$$

4. $$V = \sqrt{\frac{X^2}{t_2^2 - t_1^2}}$$

FIGURE 2

COMPRESSIONAL WAVE SEISMIC VELOCITY

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ABBREVIATIONS FOR TECHNICAL AGENCIES

STL	Space Technology Laboratories, Inc., Redondo Beach, Calif.
SC	Sandia Corporation, Sandia Base, Albuquerque, New Mexico
USC&GS	U. S. Coast and Geodetic Survey, San Francisco, California
LRL	Lawrence Radiation Laboratory, Livermore, California
LRL-N	Lawrence Radiation Laboratory, Mercury, Nevada
Boeing	The Boeing Company, Aero-Space Division, Seattle 24, Washington
USGS	Geological Survey, Denver, Colorado, Menlo Park, Calif., and Vicksburg, Mississippi
WES	USA Corps of Engineers, Waterways Experiment Station, Jackson, Mississippi
EGG	Edgerton, Germeshausen, and Grier, Inc., Las Vegas, Nevada, Santa Barbara, Calif., and Boston, Massachusetts
BYU	Brigham Young University, Provo, Utah
UCLA	UCLA School of Medicine, Dept. of Biophysics and Nuclear Medicine, Los Angeles, Calif.
NRDL	Naval Radiological Defense Laboratory, Hunters Point, Calif.
USPHS	U. S. Public Health Service, Las Vegas, Nevada
USWB	U. S. Weather Bureau, Las Vegas, Nevada
USBM	U. S. Bureau of Mines, Washington, D. C.
FAA	Federal Aviation Agency, Salt Lake City, Utah
REECO	Reynolds Electrical and Engineering Co., Las Vegas, Nevada

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